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COTTON WILT.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., July 1, 1908.

Sir: I have the honor to submit herewith a paper entitled "Cotton Wilt," which has been prepared by Mr. W. A. Orton.

This paper deals with the essential details of this subject and outlines a successful means of combating the disease through the use of wilt-resistant varieties originated by the Bureau of Plant Industry as a result of nine years' work by Mr. Orton.

I recommend the publication of this manuscript as a Farmers' Bulletin.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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COTTON WILT.

INTRODUCTION.

Names of disease known as "wilt."—The disease referred to in this bulletin has been known by other common names in various localities. It is the "blight" of the Carolina sea islands and other sections, the "frenching" described by Atkinson from Alabama, and the "blackheart" and "black-root" of the Gulf States. We shall refer to it as "wilt," because this is expressive and clear and was one of the first names applied to the disease.

This disease is quite distinct from the root-rot prevalent in the black lands of Texas, which also causes a wilting of the affected cotton plants. Neither is any reference intended here to wilting caused by drought alone.

History of wilt.—From the testimony of farmers and vague allusions in the United States Census and other reports it appears probable that the disease has been present in restricted localities in the cotton belt for at least twenty-five or thirty years. It has gained increasing headway in its spread during recent years, until complaints of loss are now frequent. The disease was not accurately described until 1892,[a] and the etiology and life history of the fungus were not worked out until studied by Dr. Erwin F. Smith, of the Bureau of Plant Industry, from 1895 to 1899.[b]

The work of this Bureau has been continued up to the present time to perfect measures for the control of this disease.[c] Corroborative experiments have been conducted by the Georgia State Board of Entomology[d] and by the Louisiana Experiment Station.[e] The present bulletin deals with practical aspects of the question with relation to Upland cotton only.

[a] Atkinson, George F. "Frenching," in Some Diseases of Cotton. Bul. 41, Alabama Agricultural Experiment Station, pp. 19–29.

[b] Smith, Erwin F. Wilt Disease of Cotton, Watermelon, and Cowpea. Bul. 17, Div. Veg. Phys. and Path., U. S. Dept. Agriculture, pp. 72, pls. 10. 1899.

[c] Orton, W. A. The Wilt Disease of Cotton and Its Control. Bul. 27, Div. Veg. Phys. and Path., U. S. Dept. Agriculture. 1900.

[d] Smith, R. I., and Lewis, A. C. "Black Root" Disease of Cotton. Bul. 22, Georgia State Board of Entomology. 1906.

[e] Fulton, H. R. Cotton Wilt. Bul. 96, Louisiana Agricultural Experiment Station. 1907.

GEOGRAPHICAL DISTRIBUTION OF WILT.

Cotton wilt is widely distributed over the cotton belt, especially in the sandy soils of the Coastal Plain. It occurs to a slight extent in eastern North Carolina and is found to be more common as one travels southward to Florida and westward to southeastern Alabama. From there to eastern Texas it diminishes somewhat in prevalence.

The accompanying map (fig. 1) shows these facts graphically. Each dot marks a locality where wilt is known to occur. The distribution of the disease is without doubt wider than here shown. Attention is called to the relation between geological and soil factors and the occurrence of wilt as indicated by the line which marks approximately the boundary of the Coastal Plain. Most of the coun-

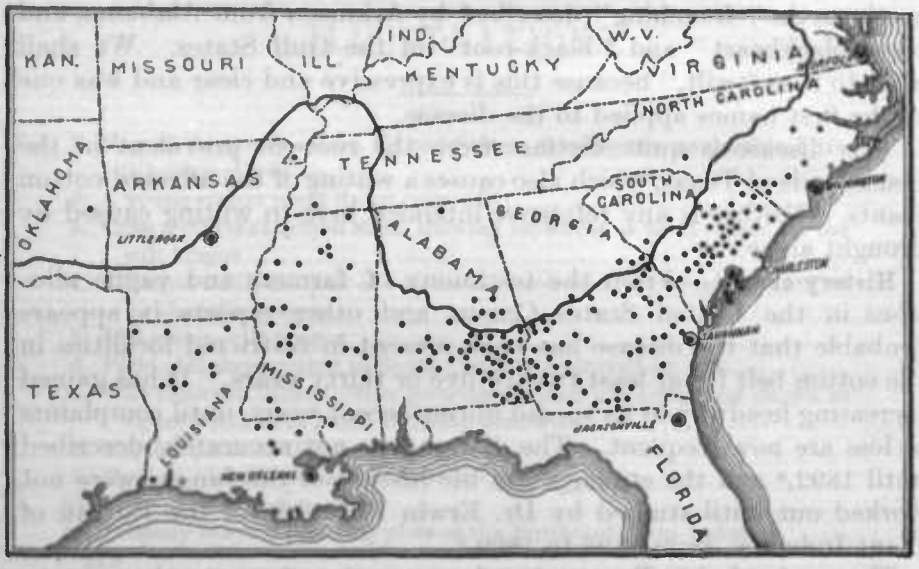

FIG. 1.—Map of the southeastern United States, showing the geographical distribution of wilt.

try south and east of this line is level, with sandy soils of alluvial origin, and was originally covered with pine forests. Here wilt is most prevalent. The country north and west of this line is the Piedmont Plateau, consisting of rolling hills, with clay soils predominating and formerly covered with oak and other deciduous trees. Wilt is quite rare in this section, occurring mainly on scattered areas of sandy and alluvial soils. Undoubted cases of wilt have been found in Tennessee, Arkansas, Missouri, and Oklahoma, however, and there is little doubt that the disease can develop in any congenial soil. In Mississippi it appears to be more prevalent along the eastern edges of the Yazoo Delta than elsewhere.

Cotton wilt is not present on all the farms in any of the communities mentioned. In some cases only a small percentage of the land is infected, but the diseased areas are steadily enlarging.

Occurrence of wilt in foreign countries.—Cases of what was thought to be this disease have been reported from Egypt and other parts of Africa, and from Turkestan in Asia. The identification of these troubles as the American wilt has not yet been definitely settled.

AMOUNT OF LOSS FROM WILT.

It is very difficult to estimate the total loss from cotton wilt. The injury varies from the death of a few plants to the destruction of hundreds of acres. Several factors are to be considered in estimating the loss. We must add to the actual shortage of the crop in the spots where the cotton dies: (1) A diminished yield of the surrounding cotton due to the dwarfing of the plants from partial infections; (2) a lessened income to the farmers on account of the necessity of planting on infected land some less profitable crop, such as corn, or of throwing cotton out of cultivation altogether; (3) the increased cost of cultivation of wilt-infected spots due to the foothold obtained by crab-grass, nut-grass, cockleburs, and other weeds, after the death of the cotton; (4) a depreciation in the market value of wilt-infected land.

These losses probably amount to more than $2,000,000 per annum and are annually increasing.

DESCRIPTION OF WILT.

FIELD CHARACTERS.

Cotton wilt may make its appearance on single plants in a field, but its later and most characteristic development is in definite spots of irregular size and varying area in which most of the plants slowly wilt and die. Some plants partially recover, but remain dwarfed and bushy, often one sided, while for some distance around the wilt-infected area the cotton is more or less stunted by partial root infections. Occasional plants are found to remain healthy even in the worst infected spots. Of two plants in the same hill one may die and the other live.

The disease reappears in the same place each year cotton is planted and on a larger scale. This annual appearance and spread will distinguish wilt from barren spots due to other causes, such as poor soil, shell banks, lightning, etc.

Wilt first appears in the latter part of May or in June, when the young cotton is 8 to 12 inches high. It is most prevalent during June and July, but some cases continue to develop until the end of the season.

PLANT SYMPTOMS.

The appearance of a cotton plant attacked by wilt varies somewhat, depending on the age of the plant and the severity of the attack (see fig. 2). Some plants wilt suddenly and die almost in a

day, others pass through intermediate stages, with leaves slowly turning yellow, especially around the margins and between the veins, and fall off. Often a branch near the ground makes considerable growth and partially recovers, producing a dwarf, bushy plant.

FIG. 2.—A young cotton plant dying from wilt

The roots of diseased plants are shorter than those of healthy plants, many rootlets dying back from the tips, and there is a characteristic tufting of the small rootlets due to repeated partial infection by the wilt fungus.

The most characteristic symptom of wilt is a browning of the woody portion of the stem and root as seen in the cross sections illustrated in figure 3. These discolored parts are the water-carrying vessels which have become obstructed by the development in them of the fungus causing the disease. A highly magnified section of a segment from the pith to the bark in such a stem is shown in figure 4. The network of colorless threads filling these vessels is the mycelium of the wilt fungus, which has thus cut off the water supply and killed the plant.

FIG. 3.—Cross sections of cotton stem, showing browning of wood caused by the wilt fungus. (Natural size.)

THE WILT FUNGUS.

Life history.—The wilt fungus[a] is itself a low form of plant life which has adapted itself to existence as a parasite. In its vegetative form it consists of the mycelium illustrated in figure 5, *b*, which is made up of slender threads of microscopic size. It lives in the earth on decaying organic matter until it encounters the small feeding roots of the cotton, which it enters. This fungus is fully able to penetrate healthy roots. Wounds or root-knot injuries are not necessary to infection, though plants weakened

[a] *Neocosmospora vasinfecta* (Atk.) Erw. Sm.

by root-knot may succumb more quickly to wilt. The fungus penetrates the vascular system of the root and grows upward into the stem. During the life of the host plant the fungus is mainly confined to the vessels.

Liberal provision is made for the reproduction and spread of this fungus through four different spore forms, also illustrated in figure 5. The first, or microconidia (*b*), are small, colorless spores borne on the mycelium within the vessels. The second, or macroconidia (*a*), are larger, sickle-shaped, or Fusarium spores and are borne in great numbers on oblong pink cushions on the outer bark of the stem after the plant dies and the fungus grows outward from the vessels. These two spore forms are short lived, but serve to spread the fungus widely under favorable conditions. The third form, or chlamydospore (*c*), is produced on the outside of the plant, mainly in the soil. It is thick walled and withstands drying or other unfavorable conditions. The fourth is a perfect stage, or ascospore (*e*). These ascospores are developed in sacs, or asci, within bright red, pear-shaped perithecia (*d*) on the bark of decaying cotton roots. Although visible to the unaided eye as red bodies the size of sand grains, these perithecia are difficult to find in the field, as they are not abundant except at a certain stage in the decay of the root.

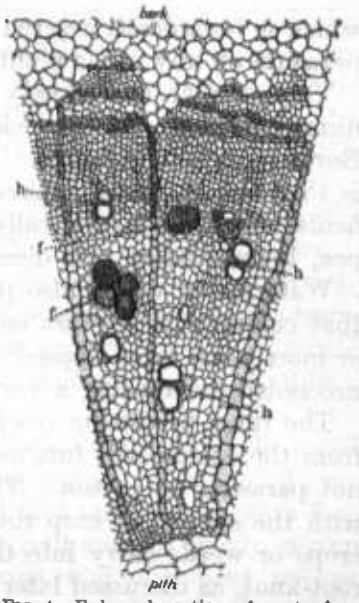

FIG. 4.—Enlarged section of part of a diseased cotton stem, showing vessels filled by the wilt fungus. Normal water vessels are shown (h) in comparison with several such vessels (f) plugged by the wilt fungus.

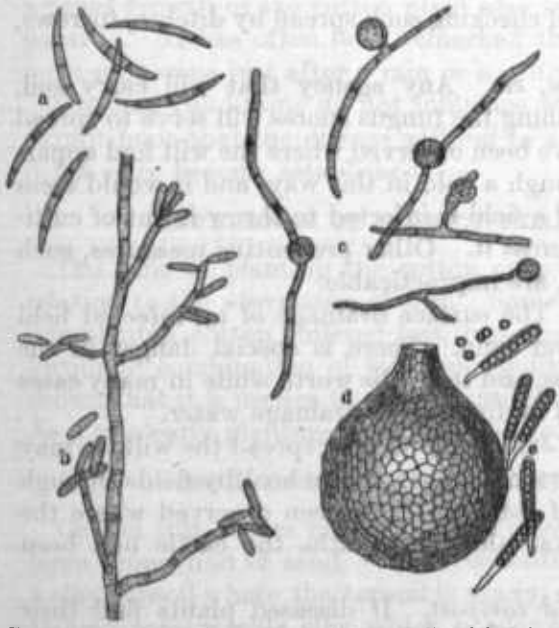

FIG. 5.—The cotton-wilt fungus. *a*, Macroconidia of fusarium stage from outer bark of dead stem; *b*, hyphæ and microconidia from vessels of freshly wilted stem; *c*, chlamydospores from bark of root; *d*, bright red perithecia from root of dead plant; *e*, asci and ascospores borne in the perithecia.

Relationship to other fungi.—The cotton wilt fungus attacks okra,

which is botanically related to cotton, but it is not known to be parasitic on any other plant.

Very similar and closely related fungi produce wilt diseases of numerous crops, as first pointed out by Dr. Erwin F. Smith, of the Bureau of Plant Industry. The cowpea wilt is of the same type. It is this disease which makes it impossible to grow peas on certain fields, which the farmer calls "peasick." One variety, the Iron cowpea, is immune to this disease and can be grown on infected land.

Watermelon wilt is also prevalent in the South to such an extent that commercial growers never plant melons after melons until ten or more years have elapsed. The Bureau of Plant Industry has just succeeded in breeding a variety resistant to this disease.

The fungi producing cowpea and melon wilt are indistinguishable from the cotton wilt fungus except by inoculation tests. They are not parasitic on cotton. This is an important point in connection with the subject of crop rotation. There is no evidence that other crops or weeds carry infection to cotton except through increasing root-knot, as discussed later in this bulletin.

Manner of spread.—The original source of infection in most communities is unknown. Once introduced, the disease spreads in several ways:

(1) *By direct growth through the soil.* The infected areas enlarge each year, in some cases several rods in a season. There appears to be no practicable method of checking such spread by ditches, furrows, or other barriers.

(2) *On cultivators, plows, etc.* Any agency that will carry soil, parts of plants, etc., containing the fungus spores will serve to spread the disease. Instances have been observed where the wilt had apparently been distributed through a field in this way, and it would seem desirable where a corner of a field is infected to throw it out of cultivation rather than drive across it. Other preventive measures, such as the disinfection of tools, are impracticable.

(3) *By drainage water.* The surface drainage of an infected field will carry the wilt to lower land. There is special danger in the overflow during heavy rains, and it will be worth while in many cases to make ditches or terraces to divert such drainage water.

(4) *On the feet of cattle.* Just as plows may spread the wilt, so may stock pastured in an old cotton field carry it to healthy fields through which they pass. Cases of this sort have been observed where the first appearance of wilt was along the paths the cattle had been accustomed to follow.

(5) *In stable manure and compost.* If diseased plants find their way to the stable the fungus will develop in the manure and be carried wherever it is put. This is very likely to happen with the water-

melon wilt through vines brought in with hay from melon fields, but the danger is less with cotton. Far too little stable manure is produced and used on a cotton plantation, but if there is any evidence that manure is spreading the wilt it would be better to use it on that portion of the farm already infected. The resistant varieties of cotton are greatly benefited by it.

(6) *By seed from infected fields.* There is no proof that wilt is spread by seed from infected fields. The fungus is not known to penetrate the seed coats. The only way seed could be infected is by contact with diseased plants covered with spores. If this were feared all danger could be avoided by soaking the seed in formalin—8 ounces to 15 gallons of water—for ten minutes, then drying thoroughly at once.

Rate of spread.—The rate of spread varies according to the conditions. In one case that has been under observation for several years and may be cited as typical, the infected area on one farm grew from 5 acres to 60 acres in five years. Cotton wilt spreads slowly in comparison with diseases like asparagus rust and cucumber mildew, which travel hundreds of miles in a season, but its infection of the soil is permanent.

INFLUENCE OF SEASONAL CONDITIONS ON WILT.

Wilt is worse on the whole in wet seasons. Conditions that lead to a rapid growth of the cotton plant also favor the development of its parasite. It has often been remarked that fresh cases of wilt were most numerous just after a rain or a cultivation.

Seasonal conditions do not influence wilt to such an extent as to permit hope that the disease will fail to appear the next season after it has once become established.

INFLUENCE OF TIME OF PLANTING ON WILT.

The time of planting the cotton crop does not bear any marked relation to the prevalence of wilt. Some farmers have thought that late-planted cotton suffered less, but these instances were due to a fortunate combination of weather conditions. Repeated tests have shown that it is useless to defer planting in the hope of escaping wilt. As a rule early planting gives the best crop.

INFLUENCE OF SOIL CONDITIONS ON WILT.

Cotton wilt occurs mainly in sandy soils or in those containing a large proportion of sand. It is frequently met with in fields having a clay subsoil where the topsoil is sandy, and more rarely in soils containing considerable clay which border infected sandy fields. It is not to be feared, however, in ordinary upland clay or clay loam soils.

Wilt is perhaps worse in thin soils than those rich in organic matter, but it does occur in rich and highly manured land, often to a very serious extent. Efforts to remedy the trouble by green manuring usually result in a great increase of the disease, but this is ordinarily due to the fact that varieties of cowpeas susceptible to root-knot are grown for plowing under. The writer has not seen the wilt on black prairie soils.

Wilt is less injurious to cotton on low land or in low spots in a field. These are richer in organic matter and are also wetter; probably both factors are involved.

INFLUENCE OF FERTILIZERS ON WILT.

It must be borne in mind that wilt is due to an active plant parasite which has no fixed connection with any farm practices in the use of fertilizers.

No reliable evidence can be brought forward to show that the disease is caused, as believed by many farmers, by the continual use of commercial fertilizer, by the use of acid phosphate, or even by continual cropping in cotton. Neither is it true that wilt is due to the absence of some element in soil fertility, such as lime, potash, or magnesium. It is due simply to the presence of the cotton-wilt fungus, the specific parasite causing the disease. This fungus plant may be viewed as a troublesome weed, and, like weeds of large size, it is likely to develop wherever its spores (the reproductive organs) are carried. If susceptible cotton plants are growing there, the cotton will become diseased.

Differences between fields have been noted by farmers and attributed to fertilizers which are rather due to changes in soil conditions. The application of stable manure has been recommended as a remedy for wilt. Our experience has been that in slightly infected fields this does give some relief, but that the wilt takes the field in the end in spite of the heaviest manuring. The use of stable manure in growing resistant varieties of cotton has been very profitable, however.

It has been positively shown that modifications of the fertilizer formula will not assist in the control of wilt. The use of acid phosphate, muriate of potash, etc., it is true, renders the soil acid, but this does not especially favor the wilt disease, for both infected and healthy fields are alike in this respect, and applications of lime to infected land at the rate of from 2 to 6 tons per acre have been made without reducing the amount of wilt. The disease also occurs on newly cleared land and in old fields that have never had any commercial fertilizer. Kainit, so valuable as a preventive of rust on cotton, has no influence on wilt. Applications of quantities amounting to 2,000 and 4,000 pounds to the acre have proved as ineffective as smaller amounts.

INFLUENCE OF FUNGICIDES ON WILT.

Soil from an infected field contains the wilt fungus, and cotton planted in it will contract the disease. If, however, such soil were sterilized by heat or by the use of chemicals, healthy cotton could again be grown. The effective sterilization of soil under field conditions presents many difficulties and has never yet been accomplished except at prohibitive cost.

In the experiments of the Bureau of Plant Industry with cotton wilt a large number of fungicides, including sulphur, copper sulphate, copper carbonate, copper acetate, Bordeaux mixture, lime and sulphur, liver of sulphur, iron sulphate, carbolic acid, and formalin were applied to wilt-infected soils in such liberal quantities that the cost of the treatment exceeded the value of the land, but in no case was the amount of wilt lessened.

It is not believed that any treatment of this sort is practicable.

INFLUENCE OF ROTATION OF CROPS ON WILT.

While the cotton-wilt fungus is not known to attack other plants, except okra, and would therefore not be likely to be carried over on other crops or on weeds, it can live as a saprophyte, feeding on decaying organic matter in the soil, for a long time, and short rotations are of little use in reducing wilt. Experience with rotations of seven to ten years has shown that the amount of wilt gradually diminishes, but no case is known where land has been entirely freed from the disease in this way.

The subject of rotation is so much more important in connection with the control of root-knot that it is treated more fully elsewhere in this paper.

RESISTANCE TO WILT.

The standard varieties of cotton differ considerably in susceptibility to wilt, but none of them are sufficiently resistant to be cultivated with profit on infected land. Extended variety tests on infected fields have shown that as a general rule the large-boll sorts, Russell, Truitt, etc., are more subject to wilt than other groups of varieties. The most resistant of the American Upland varieties tested was the Jackson Limbless, which produced about 45 per cent of a crop where other kinds failed. The original Jackson was not sufficiently resistant to justify its general cultivation, but it has been of value as a basis for breeding better races.

Egyptian cotton is more resistant to wilt than Upland cotton, but it has not as yet been found practicable to utilize this quality, as the Egyptian varieties do not succeed in our Southeastern States and it is easier to breed resistance direct from Upland varieties than from crosses with Egyptian cotton.

Differences in resistance within varieties are quite conspicuous. Observation of infected fields will show that all plants are not equally affected. Frequently two plants may be found in the same hill, one wilted, the other healthy, and even in the most severely infected spots there may occasionally be found a plant apparently resistant. In many cases these differences are due to noninfection or other temporary causes, as seed selected from such plants often proves nonresistant the next season.

RESULTS OF EXPERIMENTS IN BREEDING FOR WILT RESISTANCE.

The individual differences in cotton plants have been utilized as a basis for breeding new resistant strains. The work of the Bureau of Plant Industry has now been continued along this line for eight years, and has resulted in the successful development of two new varieties that can be grown on the worst infected land, provided a rotation of crops for the control of root-knot is practiced.

The use of resistant varieties has been shown by experiments in all the States from North Carolina to Louisiana to be a satisfactory method of combating wilt. The Bureau of Plant Industry has also shown the probability that continued breeding will result in the development of other improved strains possibly better adapted to the requirements of the section where they originate than any existing kinds.

The development of such varieties, however, is neither quickly nor easily accomplished, but requires breeding by exact methods for several years. It will not suffice to send pickers through the fields to gather seed cotton from apparently resistant plants, as some have recommended. Our experience has been that such mass selection is expensive and ineffective. Much of the seed obtained is taken from plants not truly resistant, and the succeeding crop is nearly as much diseased as the first. While such a method should result in increasing the resistance of the crop in the long run, the cross-pollination between resistant and nonresistant plants greatly delays the results. The correct method is to select with great care a small number of plants that appear to be healthy, though growing in the worst infected areas. The seed from each of these plants must be kept separate and planted in parallel rows on infected land the next year. The resulting progeny will show which of the plants selected transmits the resistant quality in the most effective manner. The rows will also vary much in productiveness and other qualities. The best one should be selected and the others discarded. In some cases a resistant row of satisfactory quality has been found the first year, and only two more seasons were required to multiply the seed, but more often complete success has not been had at once and the work had to be repeated.

The origination of new wilt-resistant varieties is work for the plant breeder rather than the general farmer, and there is need for men in every county to take up the business of breeding to supply this demand. The farmer, however, should practice selection to further improve the strain purchased from breeders, or at least to preserve it from deterioration. The Bureau of Plant Industry desires to stimulate the breeding and sale of improved varieties of cotton. To this end it will place the varieties already developed in the hands of men who will improve them and offer them for sale.

DESCRIPTION OF RESISTANT VARIETIES.

Dillon.—The first of the wilt-resistant varieties to be sent out has been named Dillon from the fact that the original selections were made in Dillon, S. C., in 1900. From 1902 to 1904 it was grown at Troy, Ala., in 1905 and 1906 at Notasulga, Ala., and during 1907 and 1908 at Lamar, S. C.

The parent variety was Jackson Limbless, a cotton greatly overexploited at the time of its introduction and not widely grown at the present time. The first variety test showed the Jackson to be much more resistant than other races of cotton, and this quality has been greatly intensified by subsequent breeding. Preliminary distributions were made in 1905, 1906, and 1907, when small quantities of seed were sent out under the name "Wilt-Resistant Jackson" for experimental trials. It was found that this name led to confusion with the unselected original Jackson and that the new strain differed from the original in being more resistant, productive, and uniform, and to some degree in having bolls less closely clustered and easier to pick, seed of darker color, etc. For these reasons the improved strain sent out in 1908 has been named Dillon. A technical description follows:

Plant tall, erect, wilt resistant, productive, often with one, two, or three large basal branches. Fruiting limbs reduced to clusters of bolls close to the main stalk. Leaves medium size; bolls of medium size, 80 being required to yield 1 pound of seed cotton. Bolls erect, seed small, average weight of 100 seeds 9 grams, covered with close, brownish green fuzz. Staple medium to short, ⅞ to 1 inch, white, straight, percentage of lint to seed cotton 37.

The group of Upland varieties having clustered bolls is not very popular among farmers, some being unduly prejudiced against it. In part, however, this feeling is accounted for by the fact that the cotton is harder to pick than big-boll varieties. This difficulty in picking is counterbalanced in part by the stormproof quality, as Dillon has held all its cotton through storms that have blown to the ground all cotton open on other varieties. Greater objections are raised on this score in sections where big-boll varieties are grown than where the prevailing kinds are of the King or Peterkin groups.

Further objection is also made to the cluster varieties because the cotton is more trashy after storms, due to fragments of the involucre adhering to the lint.

Breeders should seek to select easy-picking strains of Dillon. The bolls should also be bred to have separate pedicels, thus opening the clusters. Those who object to its faults should not lose sight of the fact that even on land not infected by wilt Dillon has been proved to rank high in productiveness, and on infected land it will yield many times as much as nonresistant kinds. A field in South Carolina where cotton had previously been a complete failure from wilt,

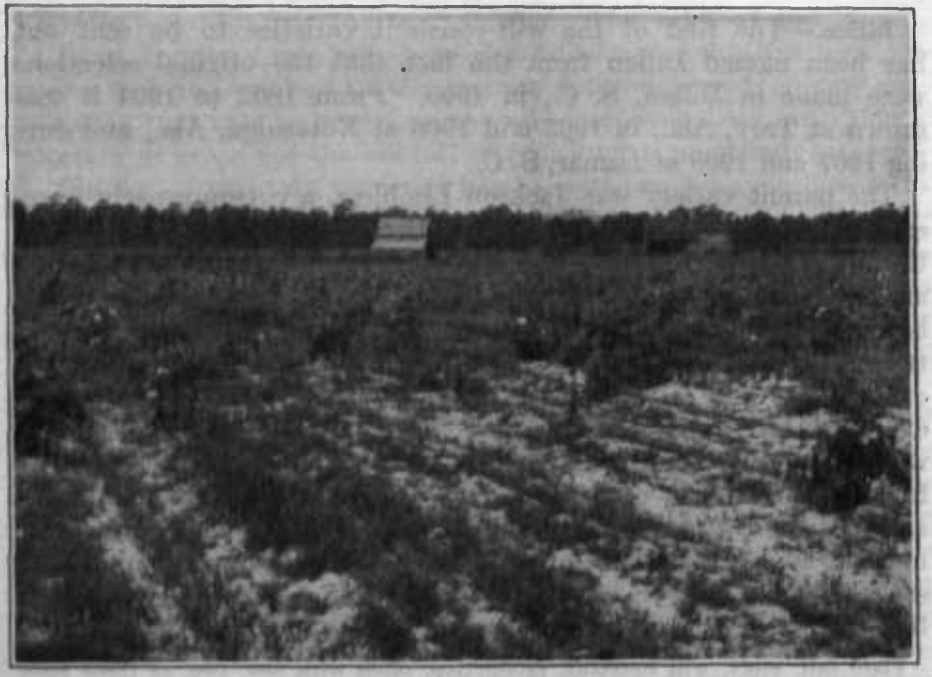

FIG. 6.—Field of Upland cotton in South Carolina destroyed by wilt.

even when highly fertilized and intensively cultivated, yielded 1½ bales per acre of Dillon cotton in 1907. (See figs. 6, 7, and 8.)

The Dillon variety appears to succeed best in the northern portion of the cotton belt, including North Carolina, South Carolina, and parts of Georgia. The southern and western portions may obtain better results from Dixie.

Dixie.—The Dixie variety is described as follows:

Plant vigorous, wilt resistant, nearly of the Peterkin type, pyramidal, with large basal branches and long, slender fruiting limbs; leaves medium size; bolls medium, 76 required for 1 pound of seed cotton, easy to pick; seed small, weight of 100 seeds 10 grams, variable in color but typically covered with greenish brown fuzz; lint 1 to 1⅛ inch, percentage of lint to seed 34. (See fig. 9.)

The Dixie variety had its origin in a selection made at Troy, Ala., of a plant presumably the result of an accidental cross between two of the numerous Upland varieties planted there in 1902. It has been bred by the progeny row method until well fixed, but should be given further selection to increase the size of bolls and general productiveness. It has proved an excellent variety in several tests in Alabama and Georgia and will in the end be more widely grown than the Dillon cotton.

Sea Island cotton.—Before the above-described Upland varieties (Dillon and Dixie) had been perfected, the problem was taken up with Sea Island cotton where the conditions with reference to resistance are much the same as with Upland cotton. Several resist-

FIG. 7.—Wilt-resistant Dillon cotton growing on land adjoining that shown in figure 6 and even worse infected with wilt.

ant strains of Sea Island cotton have been developed and are now in successful cultivation. Further details of this work are given in Farmers' Bulletin No. 302,[a] which will be sent free of charge on application to the Secretary of Agriculture.

FURTHER IMPROVEMENTS IN COTTON VARIETIES NEEDED.

There still remain many problems in connection with the breeding of wilt-resistant cotton, and it is desirable that many breeders engage in the work of producing Upland strains. The principal aims to be

[a] Orton, W. A. Sea Island Cotton: Its Culture, Improvement, and Diseases. Farmers' Bulletin 302, U. S. Dept. Agriculture. 1907.

kept in mind are earliness, larger bolls, and adaptation to particular localities.

Total immunity to wilt has not been secured in any case. Occasional plants become diseased in the best fields, but no serious loss results if selection is maintained. It is not expected that the resistant varieties bred by the Bureau of Plant Industry will maintain their resistance indefinitely unless seed selection is practiced.

In view of the threatened early invasion of the eastern cotton States by the boll weevil it is important that breeders should set about producing early large-boll strains of wilt-resisting cotton. The indications are that neither the Dillon nor the Dixie variety is early enough to fully meet the requirements of cotton culture in the presence of the boll weevil. A variety is needed which combines the wilt resistance of the Dillon variety with the large bolls, earliness, and productiveness of the Triumph cotton and which is adapted to eastern conditions, a feature apparently lacking in the Triumph variety.

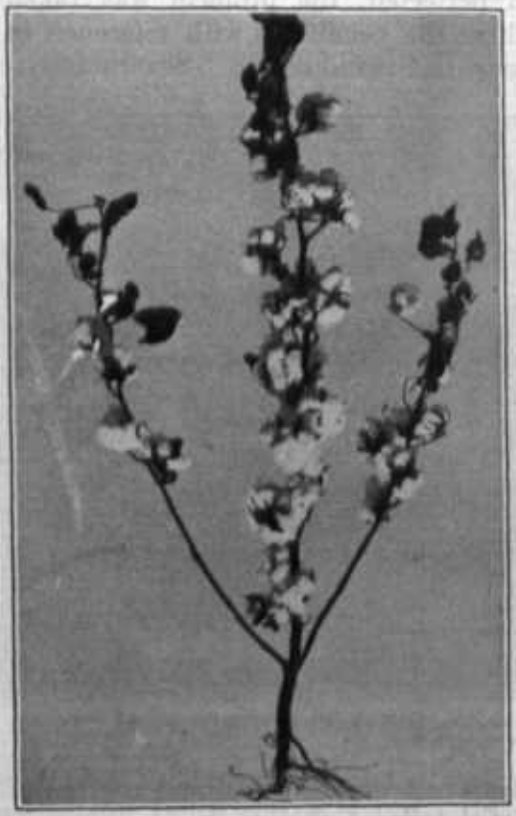

FIG. 8.—Typical plant of Dillon wilt-resistant cotton.

ROOT-KNOT IN RELATION TO WILT.

Root-knot is a disease caused by an eelworm, or nematode (*Heterodera radicicola* (Greef.) Mül.). This parasite, which is very small, from one-twentieth to one-sixtieth of an inch long, penetrates the roots and by the irritation of its presence causes the formation of irregular swellings or galls, varying in size from very minute enlargements of the small roots to knots an inch or more thick. In these swellings the worm lays numerous eggs, which soon develop. Several generations occur in a single season.

The affected plants are dwarfed. In some cases they die outright, while in others the presence of root-knot is not suspected until the roots are examined.

A great many varieties of cultivated plants and weeds are attacked by root-knot, nearly 400 species being already known to be susceptible to it. These may be very liable to injury, as is the case with celery, tomatoes, okra, cucumbers, and cowpeas, or relatively resistant, as with sugar cane and sweet potato.[a]

Cotton is moderately subject to root-knot and is so affected as to considerably reduce the yields in hundreds of fields whose owners are ignorant of its presence. The plant illustrated in figure 10 shows a typical severe case of root-knot. If such fields become infected with wilt, however, the two diseases combined will annihilate the crop.

FIG. 9.—Typical plant of Dixie wilt-resistant cotton.

The wilt-resistant varieties bred by the Department are not entirely resistant to root-knot. It is not advisable to plant them on infested land until it has first been given a rotation of two, or preferably three, years in crops not subject to root-knot, and in all cases the root-knot factor should be considered in planning rotations for sandy fields.

In all cases investigated where the wilt-resistant cotton sent out by the Bureau of Plant Industry was reported to have failed, the reason was found to be root-knot.

Root-knot is much like the wilt fungus in its soil relations, preferring sandy soils and never becoming troublesome in heavier or wet clays or clay loams. It is very common throughout the South and must be taken into account in every plan for the control of wilt.

[a] A thorough investigation of root-knot is being made by Dr. Ernst A. Bessey, of the Bureau of Plant Industry.

The principal agency in bringing about this general prevalence of root-knot in the South has been the use of cowpeas for soil improvement. The cowpea is quite subject to this parasite. The worms multiply rapidly in the roots, and each succeeding crop of peas leaves the ground in worse condition. Many farmers have already discovered this connection between the cowpea crop and their cotton disease without knowing the reason and have also observed that winter oats are beneficial, which is because they do not harbor the root-knot parasite.

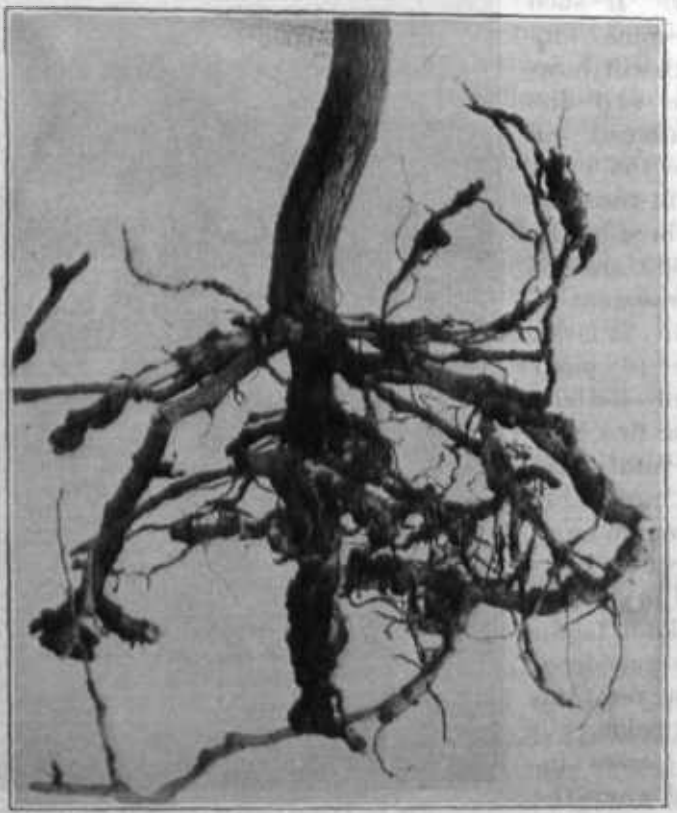

FIG. 10.—Root-knot on cotton plant. Cowpeas were grown the year before on the land on which this plant was grown.

All the common varieties of cowpeas, including the speckled or Whippoorwill, Unknown, Black, Clay, and New Era, are subject to root-knot and should be avoided throughout the territory shown in the map (fig. 1) to be liable to the wilt. This can be done without serious difficulty by the substitution of the Iron cowpea, a variety resistant to root-knot and wilt, and by the increased use of velvet beans, peanuts, and beggarweed for forage crops. New resistant cowpeas produced by hybridizing the Iron with other varieties are being developed by the Bureau of Plant Industry.

ROTATIONS OF CROPS FOR CONTROLLING ROOT-KNOT.

A rotation of crops must be worked out in detail for each farm to fit its particular needs. The essential principles to be observed are as follows:

(1) To use crops immune to root-knot, in order to starve out the pest.

(2) To build up the fertility of the soil, and especially to increase the amount of organic matter, or humus.

(3) To secure an adequate income during each year of the rotation.

(4) To keep the land free from weeds that are liable to root-knot.

A list[a] of the crops not liable to root-knot which can be used in such rotations follows: Corn, winter oats, rye, wheat, crab-grass, Iron cowpea, velvet bean, peanut, beggarweed.

Some of the crops susceptible to nematodes, and therefore to be avoided in rotations for root-knot, are cowpeas (except Iron), alfalfa, vetch, soy beans, clover, sugar cane, tomatoes, okra, cucumbers, cantaloupes, watermelons, celery, beans, sweet potato, tobacco, potato, peaches, figs, mulberry. The Iron cowpea is occasionally slightly affected in Florida, but is practically immune in the cotton belt. Seed of the Iron cowpea containing admixtures of other kinds is dangerous and should be avoided.

Bermuda grass, chufas, and summer oats are slightly susceptible, but probably can be used in rotation when root-knot is only slightly prevalent. Many weeds are also to be avoided because subject to root-knot. The commoner of these are "May-pop," "Indian potato," "saw-brier," red-root or pigweed (Amaranthus), and purslane.

The following treatment is suggested for fields infected with both wilt and root-knot:

Beginning in the fall, sow winter oats. These may be cut for hay in May or allowed to ripen. Follow the oats with Iron cowpeas, sown broadcast or, better, in drills, where they can be cultivated once or twice. Cut these peas for hay and plow the land at once for another crop of winter grain. This may be succeeded by corn, with Iron cowpeas or peanuts between the rows. The third year a wilt-resistant variety of cotton may be planted.

Wheat or rye may be substituted for oats, and the velvet bean for the Iron cowpea, especially in the more southern districts.

Considerable relief is often obtained by a single year's rotation with oats followed by crab-grass, or winter oats or rye followed by Iron cowpeas, but not all the nematodes are destroyed. However, it is much more profitable in the long run to practice a three-year rotation like that previously described.

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[a] Prepared with the assistance of Dr. Ernst A. Bessey.

BREEDING METHODS.

It will rarely be profitable for a farmer to attempt to develop a new wilt-resistant strain from a nonresistant variety, for the reason that several years of careful selection are required. A better way would be to begin with a resistant variety that the Bureau of Plant Industry has developed and modify it by further selection or cross it with a cotton possessing the desired characters. Cotton breeding will in the future be a prominent feature of the work of the Department of Agriculture and of the agricultural experiment stations, and the grower may look to them to perform the painstaking work of originating new kinds. The growers must, however, expect to continue the selection process, not only to keep the strains from mixing or deteriorating, but also to further improve them.

UNSYSTEMATIC BREEDING METHODS UNPROFITABLE.

Enough of the principles underlying plant breeding have now been discovered to show that certain methods will give the quickest and best results, and that neglect of these principles is like working in the dark and equally uncertain of accomplishing the desired aim.

Mass selection.—For example, some have advised that farmers develop a resistant variety by saving their seed by mass selection from infected fields and planting it in the same place the following year, continuing the process until the cotton became resistant. As a matter of fact, such a method would never pay or give results except by accident. The real secret of success lies in selection from individual plants and a judicious choice of the best of their offspring.

Mass selection, however, is the most common method employed by cotton planters at the present time, and consists in picking from the best plants enough seed cotton to yield, when ginned, sufficient seed for planting the next year's crop.

This is better than no selection, but will not yield the best results in the shortest time. The cotton plants in an ordinary field differ greatly in form of plant, size of boll, productiveness, and other qualities. Mass selection involves the mixing of seed from numerous diverse plants, and results in lack of uniformity in the following crop. More important still, it has been found that cotton plants differ greatly in their ability to transmit their good qualities, and mass selection does not permit the separation of plants breeding true to type from those with highly variable offspring.

The most accurate and effective method of improving a strain of cotton is by breeding from single plants of exceptional merit and proved transmitting power, i. e., pedigree breeding.

SYSTEMATIC BREEDING METHODS.

A discussion of the methods of breeding will fall into two parts: (1) How to keep pure a strain already on hand, and (2) how to improve or develop new strains.

Roguing.—The first aim is accomplished by roguing, or the removal of plants. A farmer who has secured from the Bureau of Plant Industry or elsewhere a stock of resistant seed should go through his field at least twice, when the first blossoms appear and just before the first picking, to remove all plants showing wilt and all which differ from the type of the variety. For example, in a field of the Dillon variety all plants with a different type of branching

FIG. 11.—Progeny rows in breeding plots of the Bureau of Plant Industry. Each row is planted with seed from a single plant; the center row is from a nonresistant parent plant.

should be pulled out, even though they should be resistant and productive, for our experience has been that a large part of the offspring of such plants is nonresistant. After these undesirable plants have been removed all the rest may be used for seed, except the last picking, the seed from which is likely to be immature.

Pedigree breeding.—The initial step in pedigree breeding is the choice of a considerable number of exceptionally fine plants from the general field. Consideration is given to the qualities of wilt resistance, productiveness, earliness, form, size of bolls, etc. Selected plants are marked with a white cloth and picked separately. After the last picking, a critical examination should be given the seed cotton and the total yield of each plant determined; also, the length and grade of

staple, the percentage of lint to seed,[a] and the weight of 100 seeds. At this time some of the more inferior lots may be discarded and the total number reduced to 25 or 50.

The next year the selected individual lots are to be planted separately in parallel rows of 50 or 100 hills at uniform distances. As it is important to secure a full stand, a portion of the seed should be retained for replanting.

This progeny test is the most important feature of the plan. Marked differences may be observed in the several rows (see fig. 11). Each row should be picked separately to determine its yield and should be examined critically with reference to its other characters. The best row may then be selected and the seed multiplied as rapidly as possible for general planting.

A new progeny plot should be planted each year. Many of the individual selections will naturally be made from the progeny plot of the preceding year, but some should be made from the general field in the hope of securing improvements and to bring in "new blood."

METHODS OF DISTRIBUTING SEED.

The question of distributing wilt-resistant seed in such a way that all sections may receive benefit from the work of the Bureau of Plant Industry is an important one. It is evidently out of the question for the Department of Agriculture to send seed to all who need it in sufficient quantity to plant their crops. The only solution of the difficulty is to encourage local breeders to grow and offer seed for sale.

To this end the Department of Agriculture has begun to send out seed to men who have been ascertained by previous correspondence to have wilt-infected land and to be willing to care for the seed. The quantity given to each is one peck, enough so that if planted with care by hand or with a dropper at least a bale of cotton can be raised; then this cotton can be taken to the gin and the seed saved free from mixture with other kinds.

Those receiving this wilt-resistant seed are expected to heed the advice given in this bulletin to keep the seed pure and sell to their neighbors.

As previously stated, the wilt disease is distinct from the Texas root-rot, and these cottons are not bred for resistance to root-rot; hence, they are not intended for distribution in Texas, where wilt is known to occur only in a very few localities.

[a] Consult Circular No. 11, Bureau of Plant Industry, U. S. Dept. Agriculture, entitled "Danger in Judging Cotton Varieties by Lint Percentages," by O. F. Cook. 1908.